

PREFRONTAL RAINFALL OVER NORTH CENTRAL TEXAS, MAY 12-13, 1957

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1. INTRODUCTION

During the 24-hour period ending 1230 GMT May 13, 1957 moderate to heavy convective-type rain occurred over a large portion of north central Texas. In consideration of the type of precipitation, amounts were not unusually large, ranging from 1 to 5 inches (fig. 1). However, the most interesting feature was that the rainfall area was well organized and located in an area where the surface isobars were curved anticyclonically (fig. 2) for the most part. Although cyclonic curvature usually connotes convergence and anticyclonic curvature divergence, Fletcher [2] has pointed to the existence of heavy rainfall situations in Texas wherein there is low-level anticyclonic curvature and upper-level cyclonic curvature. Such was the case over north central Texas May 12-13.

In general precipitation is the result of saturated air being lifted and is closely associated with horizontal convergence in the low levels and divergence in the upper levels. In addition to topography, the lifting of air can be accomplished by fronts, thermal instability, and isobaric convergence. This investigation has been limited to a synoptic analysis of features related to these lifting processes to determine why north central Texas was a preferred area for moderate to heavy precipitation from 1230 GMT May 12 to 1230 GMT May 13. The synoptic analysis included the general features of the surface and upper-air patterns, stability factors, moisture considerations, upper-level wind field with vorticity concepts, low-level wind distribution, and a system of trajectories for delineating low-level convergence.

2. SURFACE FEATURES

The pressure pattern over Texas and adjacent areas changed very little during the 24-hour period being investigated. In general, there was a weak, slow-moving low pressure center in the Colorado-Kansas area and a quasi-stationary Low over northern Mexico (fig. 2). A cold front was oriented from north to south through western Texas and remained almost stationary west of a line through Altus, Okla., San Angelo, and Del Rio, Tex., until about 0900 GMT May 13. Then the front accelerated and moved to a line near Fort Worth and Waco by 1500 GMT May 13. Surface isobars in the warm sector suggested a south to southeast flow of air into Texas and exhibited anticyclonic curvature over north central Texas.

Both temperature and moisture were reported above normal at stations in the warm sector. The available surface moisture was very pronounced, with dewpoint values ranging from the upper sixties to the lower seventies. This was considerably higher than the 53° F. dewpoints which are considered the critical moisture index for tornadoes and severe thunderstorms [12].

There was little evidence in the surface data that a well organized instability line existed. There was an absence of marked wind shears and large changes in pressure that are normally associated with instability lines. It was noted, however, that radar reports around 0000 GMT May 13 outlined an area 30 miles wide of broken, moderate to strong echoes extending from Sherman, Tex. over Dallas to 30 miles north-northwest of Waco. Hail was indicated in strong echoes 10 miles east of Dallas and 15 miles east of Sherman. Two short lines of broken echoes were also observed. One was of moderate intensity, 8 miles wide, and extended from 10 miles east of

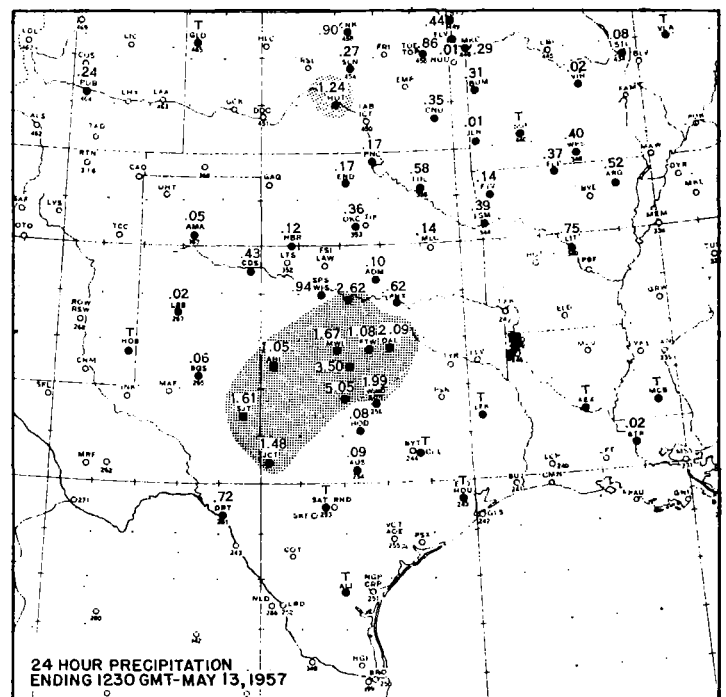


FIGURE 1.—24-hour precipitation amounts for period ending at 1230 GMT May 13, 1957. Area which received one inch or more of rain is shaded.

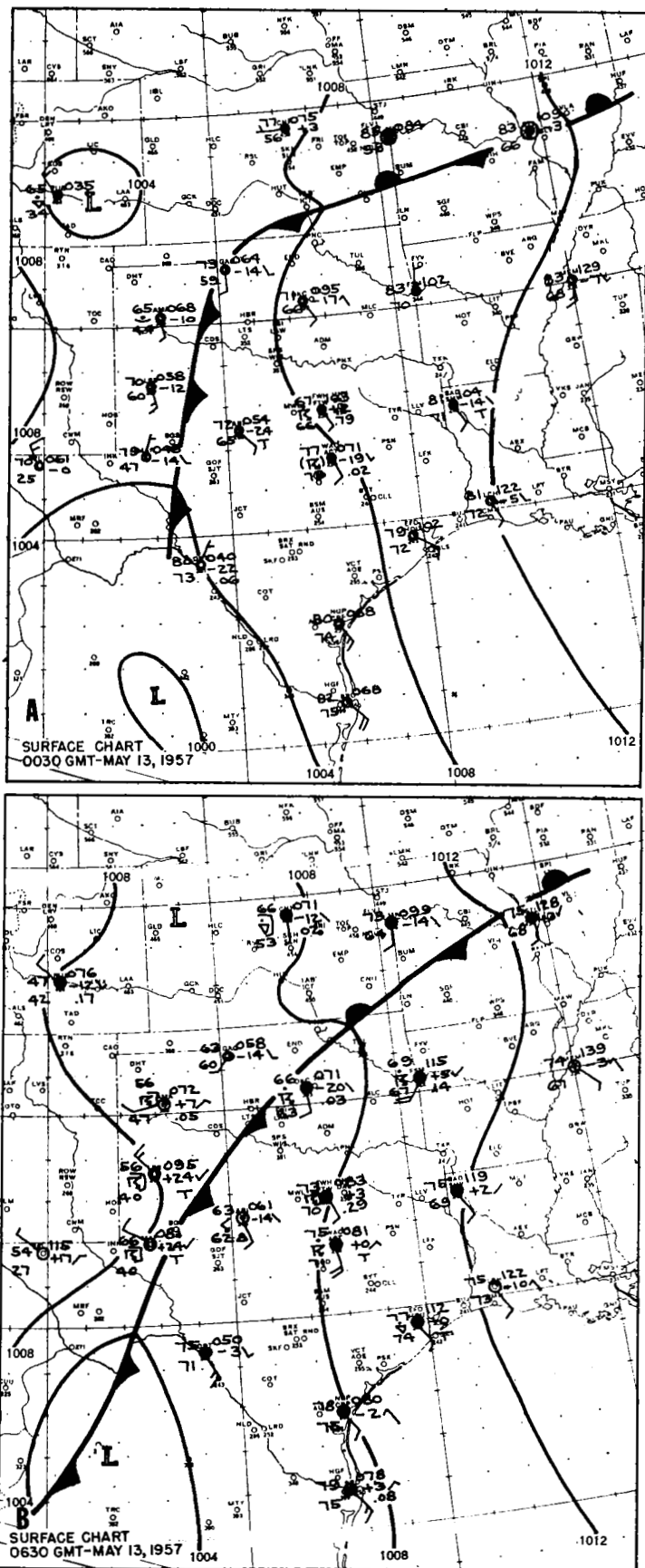


FIGURE 2.—Surface charts for May 13, 1957. (a) 0030 GMT, (b) 0630 GMT. Anticyclonically curved isobars and high dewpoints were dominant over north central Texas.

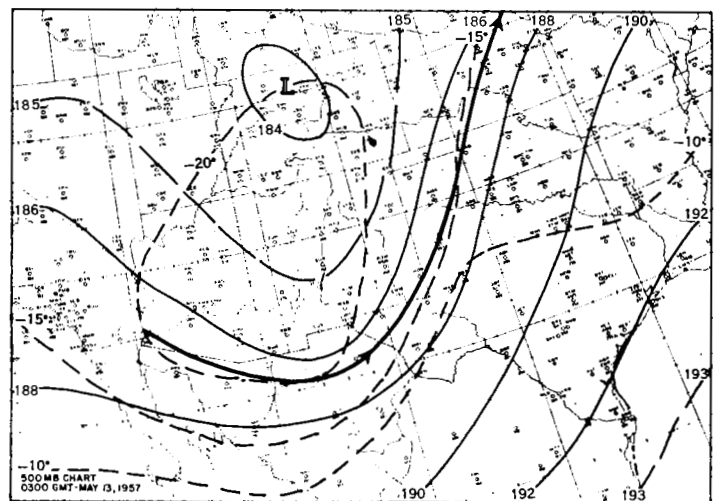


FIGURE 3.—500-mb. chart for 0300 GMT May 13 showing warm air advection (dashed lines) and cyclonically curved contours over north central Texas. Axis of maximum winds is indicated over the Texas Panhandle.

Ardmore, Okla. to 40 miles southeast of Wichita Falls, Tex. The other was strong in intensity, 20 miles wide, and extended from 40 miles south of Mineral Wells, Tex. to 45 miles east-southeast of Junction, Tex. Because the thunderstorm activity was fairly general over the area, hourly continuity of the short squall lines, as well as of the individual cells, was almost impossible. Miscellaneous radar echoes of cells and very short lines were also observed along and ahead of the cold front from Altus to Del Rio.

3. UPPER-LEVEL FEATURES

At the 500-mb. level, a closed Low, located over southeastern Utah at 1500 GMT on the 12th, had moved to central Colorado by 0300 GMT on the 13th with its associated trough extending southward (fig. 3). Cyclonically curved contours prevailed over Texas, a favorable condition for precipitation according to the Olivers [5]. Prior to 1500 GMT May 13, the 500-mb. departure from normal charts showed that heights over extreme western Texas and the Texas Panhandle were 200 ft. below normal, while over north central Texas they were near normal. Cold air advection was indicated in the El Paso-Big Spring area while warm air advection was indicated over north central Texas (fig. 3). A model for pronounced convective instability [5] has been one in which warm air advection is indicated up to the 700-mb. level and then cold air advection up through the 500-mb. level. In this case the 500-mb. thermal pattern did not support the model since there was apparently no cold air injection to trigger the rain-producing mechanism.

The temperature departures from normal were also examined since it was possible the air could have been unusually unstable even though the 500-mb. level lacked cold air advection. On May 12 and 13, when the surface temperatures were above normal ahead of the cold front,

the 500-mb. temperatures were either normal (10-year mean) or a degree above normal. As would be expected, this same pattern was verified by the departures from normal of the 1000–500-mb. layer which showed normal thickness (i. e., mean virtual temperature) ahead of the cold front.

An analysis of the vertical wind structure over Fort Worth at 2100 GMT, prior to a period of heavy rain, indicated mean warm advection from the surface through the 500-mb. level. In detail, however, veering winds indicated warming up to the 850-mb. level, then weak cold air advection was shown as the winds backed slightly to the 700-mb. level, and finally warming again up through the 500-mb. level, as the winds veered with height once more.

This pattern of wind distribution and temperature advection suggested the possibility of an upper cold front forming along a narrow tongue of cold air extending far ahead of the surface cold front; however, a synoptic analysis of the surface and upper-air data did not verify this conclusion satisfactorily. Likewise, radar observations which followed the period of heavy rain at Fort Worth did not disclose the presence of a well organized line of echoes that might be expected along an upper cold frontal surface.

4. STABILITY FACTORS

In general, the Showalter Stability Index [10] in north central Texas was characterized by large fluctuations from 1230 GMT May 12 to 1230 GMT May 13. The 0300 GMT stability index chart (fig. 4) shows the instability pattern near the midpoint of the 24-hour period. As might be expected, the air appeared to be unstable ahead of the front; however, it was more stable than expected in north central Texas, especially at Fort Worth. Actually the 2100 GMT sounding at Fort Worth (fig. 5a) showed a moist layer up to the 750-mb. level, and correspondingly, a stability index of -4 . During the next 6 hours, Fort Worth received over an inch of rain and most of the low-level moisture was apparently lost (fig. 5b). The stability index at this time, 0300 GMT, jumped to $+2$. Then 6 hours later, moisture had been restored to the 850-mb. level, and the 0900 GMT stability index was computed as -6 . This value seemed much more representative of the instability present in the warm sector.

While acknowledging the value of the Showalter Stability Index the Severe Local Storm Center [12] has suggested that the method of computing stability can sometimes be misleading since it is based on the moisture at the 850-mb. level instead of the mean moisture in the low levels. They have found that values of the Showalter Stability Index equal to or greater than $+6$ indicate convective stability, while smaller positive values may be either convectively stable or unstable. A check of the Fort Worth sounding for 0300 GMT May 13 (fig. 5b) showed that the wet-bulb temperature decreased more rapidly

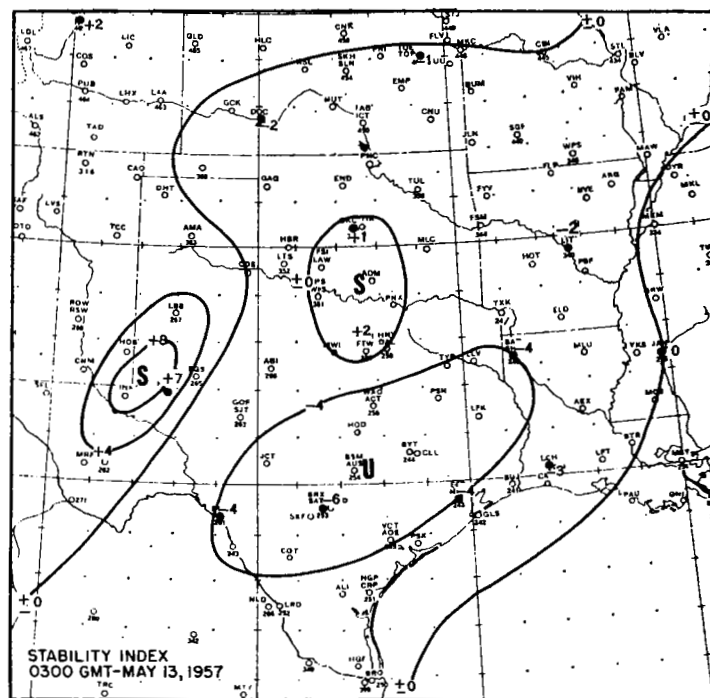


FIGURE 4.—Showalter Stability Index chart for 0300 GMT May 13, which indicated convectively unstable air over Texas ahead of the front.

with height than the moist adiabatic rate and thereby indicated the air with the $+2$ stability index was convectively unstable.

5. MOISTURE CONSIDERATIONS

As previously mentioned, surface dewpoints over Texas ahead of the cold front suggested an ample supply of moisture. Furthermore, the amount of precipitable water in the air over Fort Worth, based on the 2100 GMT sounding (fig. 5a), was computed [13] to be 2.00 inches up to the 750-mb. level. This figure was in general agreement with the reported rainfall in the Fort Worth-Dallas area around 0000 GMT May 13. Fort Worth received 1.08 inches and Dallas 2.09 inches of rain.

A more detailed analysis of the moisture field at the 850-mb. level for 1500 GMT on the 12th (fig. 6a) showed an area enclosed by a line through Corpus Christi, Big Spring, Abilene, Fort Worth, and Fort Smith, having dewpoint depressions of 4° C. or less, with values ranging from zero at San Antonio to 3° C. at Fort Worth. The axis of maximum saturation appeared to be along a line from San Antonio to Fort Smith. By 0300 GMT on the 13th the moist axis had shifted eastward to a line through Shreveport and San Antonio, while the air at Abilene and Big Spring was quite dry with dewpoint depressions of 15° C. or more (fig. 6b). Fort Worth was somewhat drier than it was 6 hours earlier, having a depression of 9° C.

At the 700-mb. level the moisture field (dewpoint depressions of 6° C. or less) was characterized by a moist tongue about 180 miles wide from Del Rio to Altus (fig. 6c)

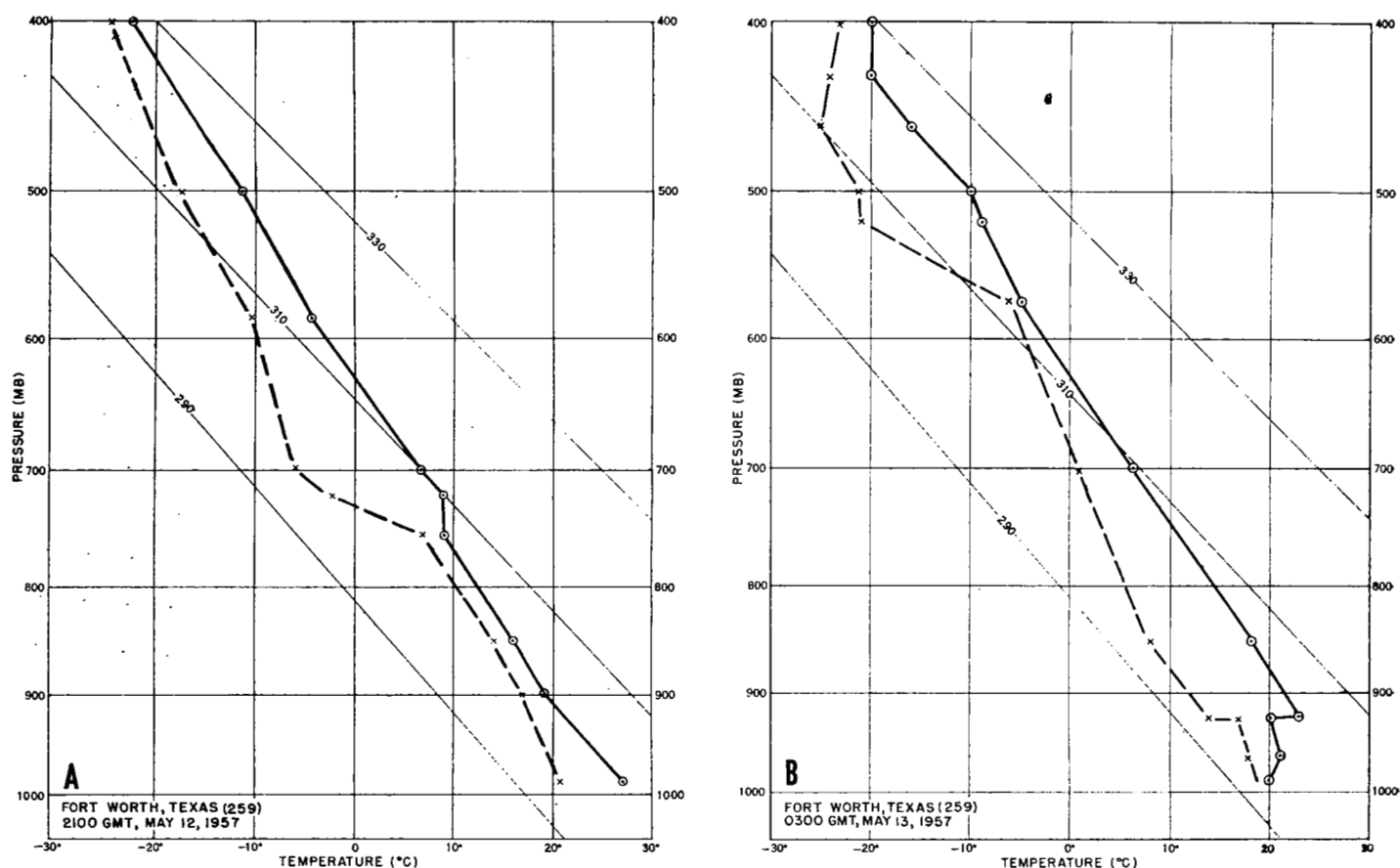


FIGURE 5.—Upper air soundings for Fort Worth, Tex. (a) 2100 GMT May 12, and (b) 0300 GMT May 13. Soundings showed availability and depletion of moisture before and after a heavy rain. Stability indexes were -4 and $+2$ respectively.

and a dry tongue of about the same width from Corpus Christi to Fort Smith. Fort Worth had a dewpoint depression of 11°C . Twelve hours later this moist tongue (fig. 6d) had shifted eastward to a line near San Antonio and Fort Worth.

On the 500-mb. chart there was much less moisture indicated than at the other standard levels. At 1500 GMT May 12 the air east of a line through Amarillo and Big Spring was dry with dewpoint depressions less than 15°C . A new surge of moisture with dewpoint depressions of 8°C . or less prevailed over Arizona. By 0300 GMT on the 13th, this area of moisture had spread into New Mexico and Kansas while a dry area prevailed south of a line through El Paso, Big Spring, and Lake Charles. Fort Worth at this time had a dewpoint depression of 11°C . During the next 12 hours, the moisture area moved into Oklahoma and Kansas with a narrow tongue dipping southward over north central Texas.

The model for severe storms [12] has provided a combination of conditions favorable for the development of intense convective activity. These conditions have included the requirement of low-level moisture, a middle layer of dry air, and some moisture at the upper levels. It has been suggested that if there is sufficient moisture in the upper levels to support a triggering mechanism for

thunderstorms, it would tend to establish a chain reaction. The middle layer of dry air would be cooled to its wet-bulb temperature by the falling precipitation. The increased density of the air would then be used to support down-currents, which in turn would add to the convective up-currents. In this case, the moisture requirements of the severe storm model were apparently fulfilled.

6. UPPER WIND FIELD AND VORTICITY

In the upper wind field, the 500-mb. jet axis was curved cyclonically along a line near El Paso, Big Spring, and Amarillo, at both 1500 GMT May 12 and 0300 GMT May 13 (fig. 7). The 200-mb. jet axis was similarly located. Riehl and others [8] have related the jet stream to precipitation and have found that an area ahead of the upper trough and to the left of the current is a preferred spot. In this case, it appeared that the jet stream model bore little relation to the situation being examined, especially since the rain seemed to be of a convective type.

The upper wind field was also inspected with respect to the vorticity field and its relation to precipitation. In the examination of this relationship, Petterssen's rule [6] of positive vorticity advection and its effect on surface pressures and vertical motion was used as a model. Petterssen has said that cloudiness and precipitation

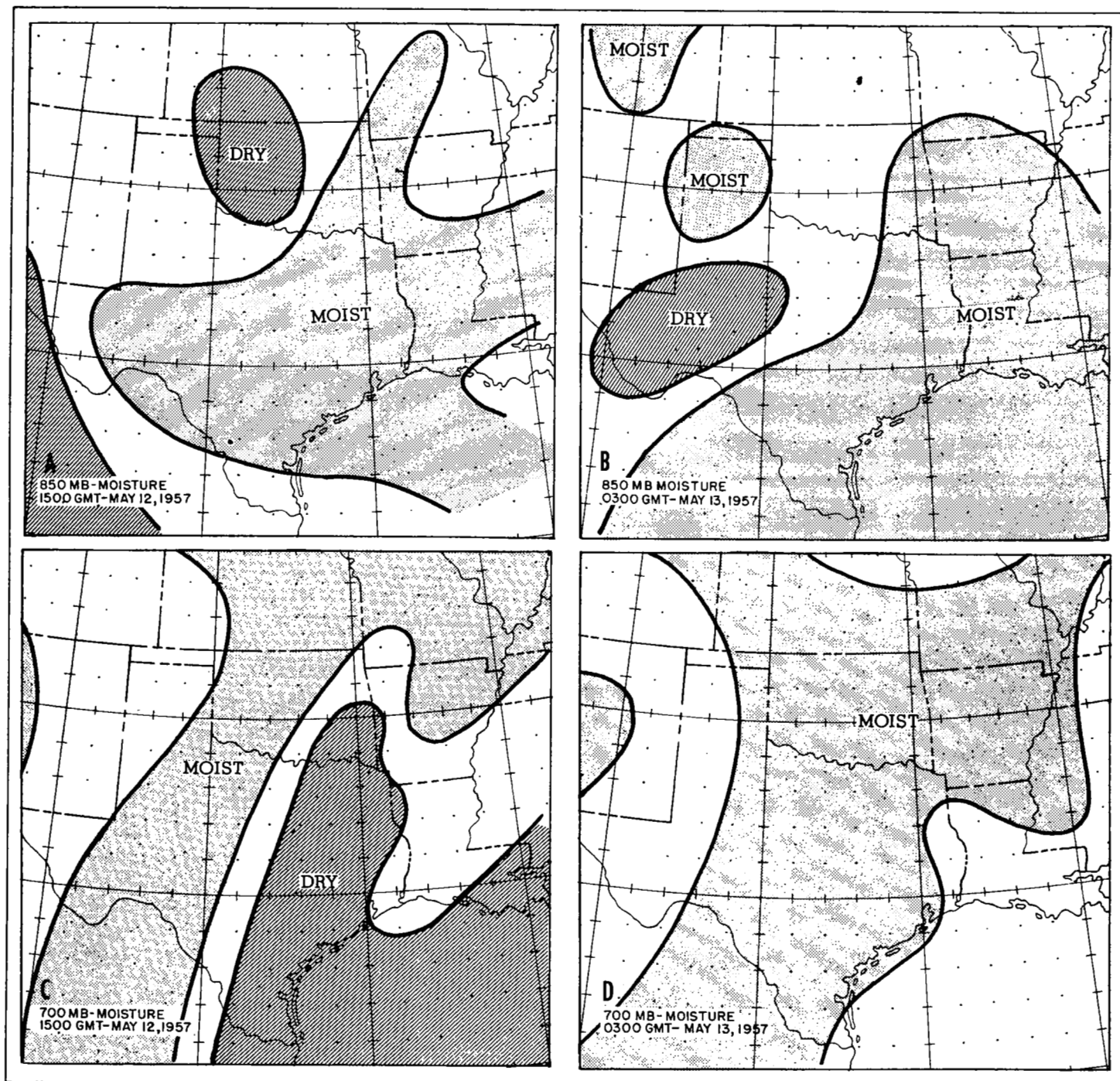


FIGURE 6.—The distribution of moisture is indicated for the 850- and 700-mb. levels. Dry areas were those having a dewpoint depression of 15° C. or greater. (a) 1500 GMT May 12, 850-mb. pattern. Moist area indicated by dewpoint depression of 4° C. or less. (b) 0300 GMT May 13, 850-mb. pattern. (c) 1500 GMT May 12, 700-mb. pattern. Moist area indicated by dewpoint depression of 6° C. or less. (d) 0300 GMT May 13, 700-mb. pattern.

should exist in an area where the relative vorticity decreases downstream, and has implied that it is the advection of vorticity that is important. Riehl et al. [7] have suggested that a vorticity gradient of at least $5 \times 10^{-5} \text{ sec}^{-1}$ over 10° of latitude is needed for the rule to work successfully. In this case, the vorticity charts used at NAWAC showed almost no vorticity gradient at the 500-mb. level

over Texas until about 1500 GMT May 13, when the 500-mb. trough increased in amplitude and began moving eastward. It was evident then that the vorticity advection had been increased over most of Texas.

Although the geostrophic vorticity gradient over north central Texas was quite weak, a certain amount of low-level convergence and vertical motion was implied from

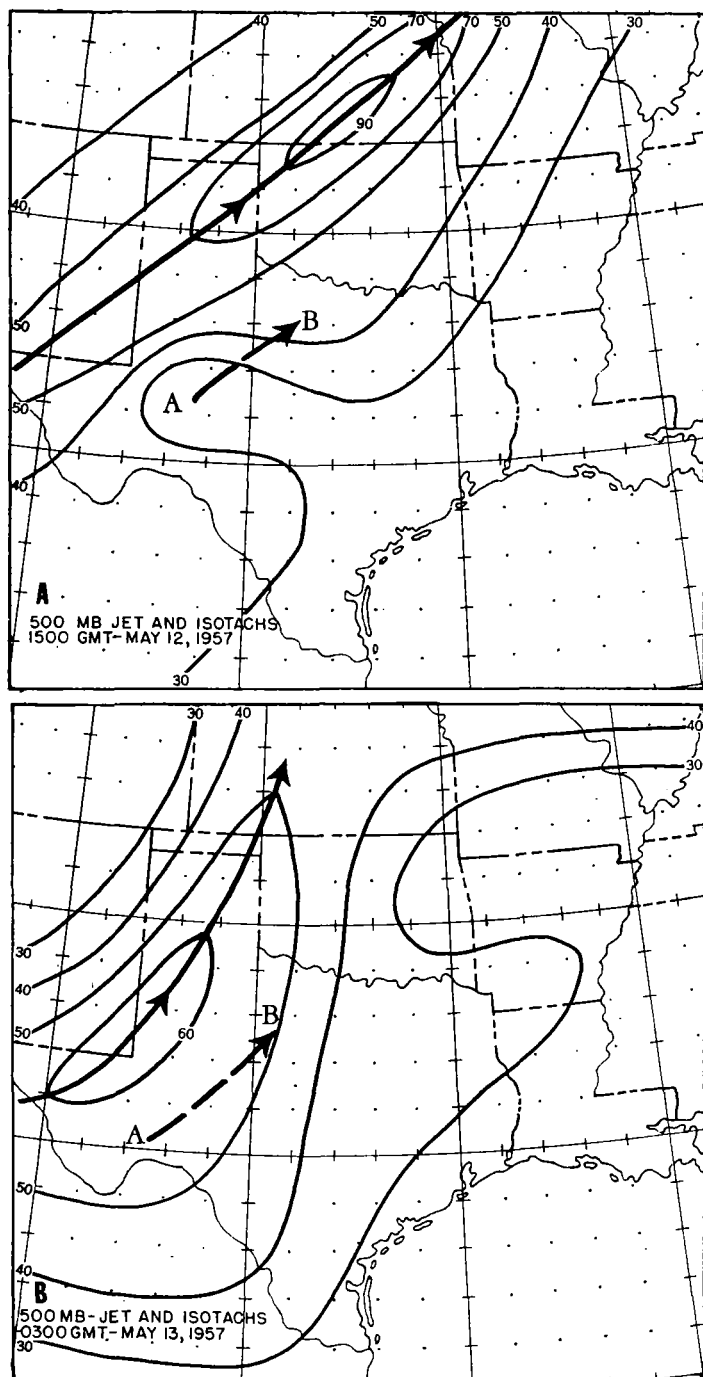


FIGURE 7.—500-mb. jets and isotachs for (a) 1500 GMT May 12 and (b) 0300 GMT May 13. At 1500 GMT north central Texas appeared to be in a favorable position for some cyclogenetic activity, as air moving from A to B would experience increasing anticyclonic shear and decreasing cyclonic curvature. At 0300 GMT the area was less favorable.

the actual winds of the 500-mb. isotach field (fig. 7). Riehl et al. [7], using Scherhag's and Sutcliffe's models which relate upper level vorticity to surface pressure changes, states that surface pressure falls occur where the advection of vorticity decreases downstream at the upper levels. The equation of relative vorticity

$$\zeta = \frac{V}{R} - \frac{\Delta V}{\Delta n}$$

was qualitatively applied to the 500-mb. isotach field for 1500 GMT May 12 and 0300 GMT May 13. In the equation V is wind speed, R is radius of curvature, and n is distance normal to the flow and positive to the left. At 1500 GMT (fig. 7a), a zone of divergence was located over the San Angelo area as shown by a decrease in wind speeds. It appeared therefore, that an air parcel transported from point A to point B would be moving into an area of greater anticyclonic shear. At the same time, the cyclonic curvature of the 500-mb. contours was decreasing downstream over north central Texas (fig. 3). A combination of these two features showed high level divergence and favored surface pressure falls, upward motion, and precipitation in the area adjacent to Abilene. As a matter of interest, there were numerous reports of 2 to 2½ inches of rain in the Abilene area.

At 0300 GMT May 13 (fig. 7b) the area adjacent to Abilene appeared less favorable for low-level cyclogenetic activity, shown by a decrease in anticyclonic shear from point A to point B. The only other area indicative of low-level convergence was that beneath the upper-level divergent area that had moved to the north and northeast of Fort Worth.

7. LOW-LEVEL WIND FIELD AND CONVERGENCE

The importance of the low-level wind field in relation to precipitation has been mentioned by several investigators. The Severe Local Storm Center [12] has noticed that the apparent intersection of the upper-level jet and the low-level jet represents an area of intense convective activity and severe weather. In this case, there was no evidence of a higher jet being superimposed on the lower jet. Riehl et al. [7] have observed that the area of maximum precipitation usually lies to the left of the low-level jet from the south. This observation is verified by figure 8 which shows the low-level jet east of north central Texas.

At 1500 GMT May 12 the axis of the 850-mb. jet (fig. 8a) was located over eastern Texas and coincided reasonably well with the axis of moisture at this level (fig. 6a). An area of slow wind speeds prevailed over north central Texas and suggested the possibility of low-level convergence in the Fort Worth region. By 0300 GMT, the jet axis had shifted westward (fig. 8b) as the 850-mb. frontal trough sharpened and the wind field over Texas was better organized. With the exception of the frontal trough, there was little evidence of convergence over Texas at this time. On the 850-mb. chart for 1500 GMT May 13 (fig. 8c) the organization of the front and wind field appeared to fit the classical model with a wide zone of convergence indicated ahead of the front.

Fulks [4] states that mere instability is not the only requirement for thunderstorm activity and suggests that a triggering mechanism may be found in low-level con-

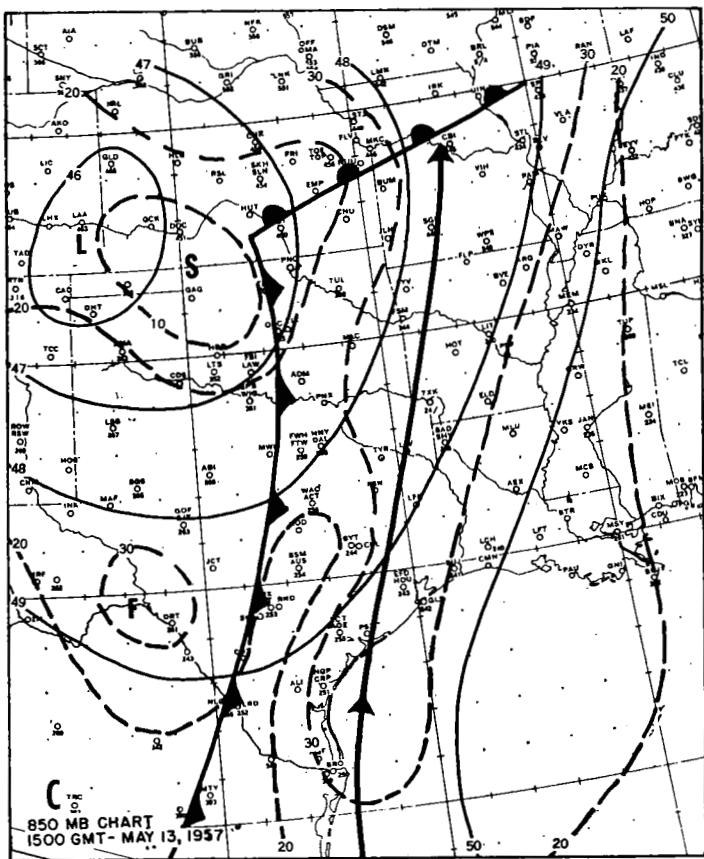
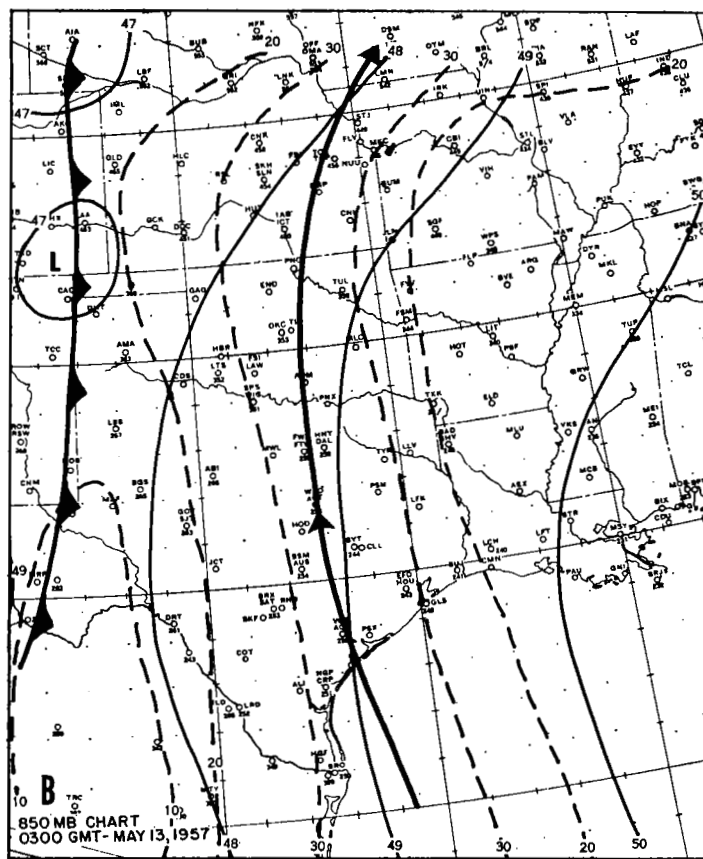
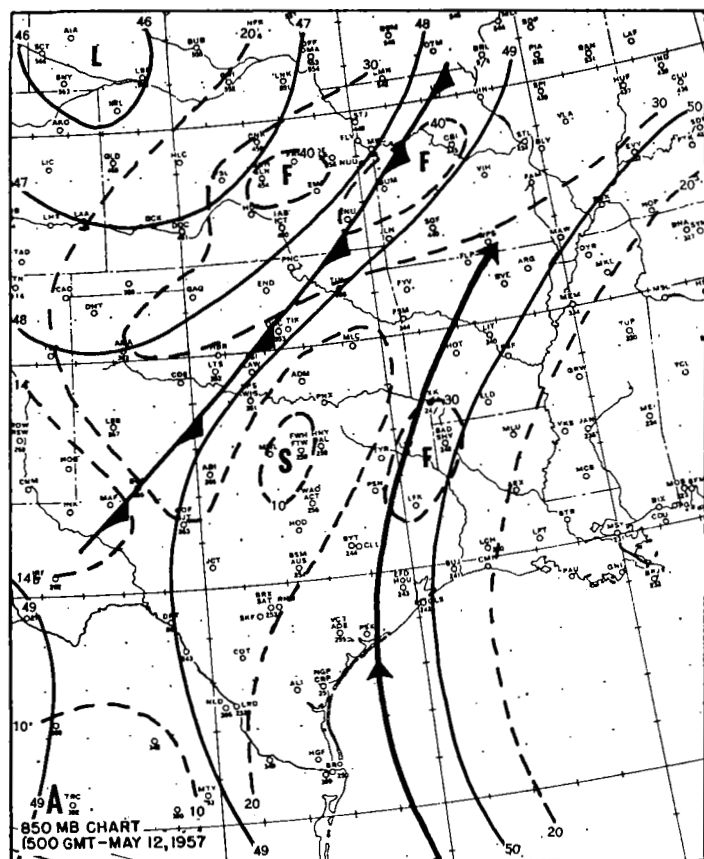


FIGURE 8.—850-mb. flow pattern and distribution of isotachs (dashed lines) for (a) 1500 GMT May 12, (b) 0300 GMT May 13, and (c) 1500 GMT May 13. Area of maximum rainfall occurred to left of low-level jet.

vergence. An approach to qualitative low-level convergence is found in Bjerknes's classical model of the relationship between wind flow and isobaric gradient. According to the relationship, a moving air parcel is turned to the right by the Coriolis force unless the pressure gradient exceeds this force and causes the parcel to be deflected to the left. Or, more simply, an air parcel moving into a weak pressure gradient will be turned to the right while one moving into a strong pressure gradient will be turned to the left. From May 12 to 13 the surface pressure gradient to the east of Fort Worth and Waco appeared to be somewhat stronger than that to the west (fig. 2). This suggested that the air flowing northward from the Houston area would be turned to the left as it approached the Fort Worth area. Qualitatively, an area of convergence is indicated in the general region outlined by Waco, Fort Worth, and Abilene, which, incidentally, was within the area of maximum precipitation (fig. 1).

To further delineate the area of maximum convergence, systems of air parcel trajectories were constructed (figs. 9 and 10). These trajectories were based on principles described by the Air Weather Service [11] and by France-

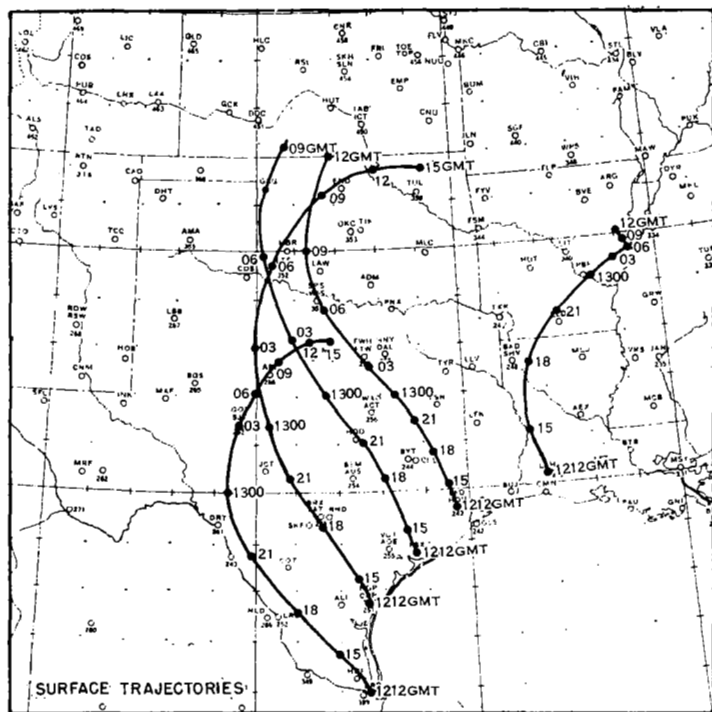


FIGURE 9.—Low-level convergence over north central Texas is indicated by a series of air parcel trajectories near the surface. Computation of parcel trajectories began at 1230 GMT May 12 and covered 3-hour intervals.

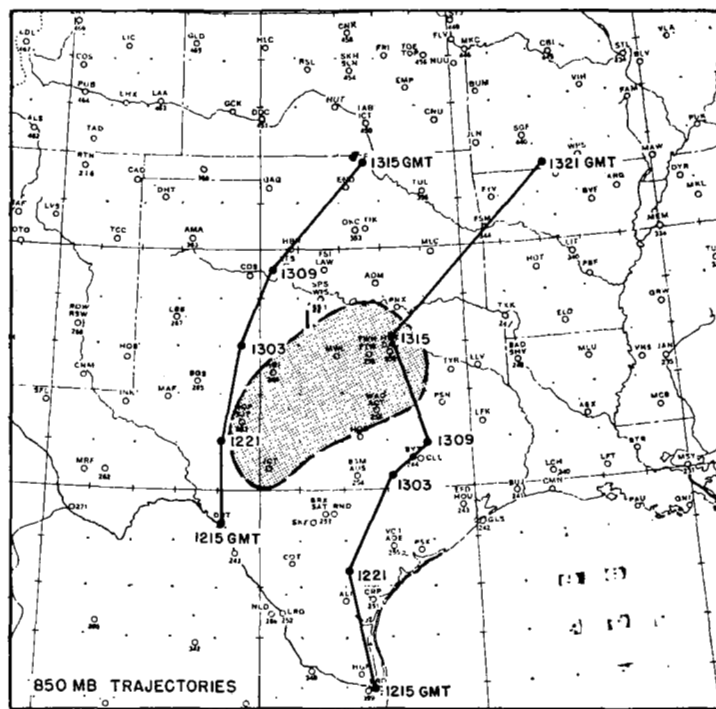


FIGURE 10.—Cyclonic turning of air parcel trajectory at 850-mb. level suggested the general area of heaviest 24-hour precipitation. Computations of parcel trajectories were for 6-hour intervals beginning at 1500 GMT May 12.

schini and Freeman [3], which include accelerations such as the Coriolis effect but neglect surface friction and vertical motion. To minimize frictional effects, the gradient-level wind was used as the initial or actual wind in the construction of the surface trajectories. As expected the air parcel was turned cyclonically to the left where the geostrophic wind component exceeded the actual wind and to the right where the actual wind exceeded the geostrophic.

In the application of the trajectory patterns to the rainfall situation of May 12–13, two concepts of convergence were considered. One was “channel convergence” or the time rate of change in area divided by the area; and the other was that described by Rossby [9] in which convergence is denoted by a change in vorticity resulting from wind shear and/or curvature. Appleby [1] has pointed out that cyclonic turning of air parcels defines the area of maximum precipitation.

At the surface (fig. 9) the air parcels originating along the Texas Gulf coast began areal convergence along a line just south of Junction and Waco, which agreed reasonably well with the southern boundary of the precipitation area. The western boundary of the precipitation area was defined by the areal convergence of the parcels from San Angelo to Altus. Rainfall amounts to the south of Abilene, apparently a maximum convergence area, were over 2 inches as compared with 1.61 inches at San Angelo and 1.05 inches at Abilene.

Although the trajectory of air parcels from Houston and Palacios did not cross each other, convergence was suggested by an increase in parcel speed with some cyclonic turning. This feature appeared about 2100 GMT between Bryan and Waco. In accordance with Appleby's observations, the maximum reported rainfall, 5.05 inches, occurred near Waco in the area adjacent to cyclonic turning.

Evidence of low-level convergence to the north and northeast of Fort Worth was not as obvious as that in other areas. Since this area experienced tornadoes, hail, and up to $3\frac{1}{2}$ inches of rain, it was assumed that low-level convergence was present. Divergence was observed at the 500-mb. level (fig. 7b) in this area and thus agreed with the assumed pattern of low-level inflow.

Trajectories were also computed for the 850-mb. level (fig. 10), using an interval of 6 hours rather than 3. The results were not as impressive as those at the surface, except to indicate cyclonic turning near Waco where the largest 24-hour precipitation was reported.

8. CONCLUSION

During the period 1230 GMT May 12 to 1230 GMT May 13, Texas was a potential rain area. The air was convectively unstable and laden with low-level moisture. The lifting processes causing the rain were interrelated, but the main contribution apparently resulted from low-level convergence induced by wind shears and changes in curvature.

In this case, the trajectory patterns were helpful in outlining the areas of low-level convergence and indicating that north central Texas was a preferred region for precipitation.

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